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Environmental Performance and Climate Policy

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Environmental performance and climate policy[1]

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Abstract

This study's ultimate goal is to analyze environmental performance (*EP*) at firm level and the effectiveness of environmental policy along with other possible determinants. Especially, the empirical analysis aims at exploring the relationship between the actual *EP* of firms in terms of CO_2 emissions per output unit, and one aspect of Swedish environmental policy, the CO_2-tax. Since Sweden was the first country to introduce a specific CO_2-tax in 1991 we believe that the Swedish case may serve as an appropriate "test bench" for analyzing *EP* and the effectiveness of environmental policy in general. To achieve our objective we use a panel data of Swedish manufacturing spanning over the period 1990-2004. The results suggest that *EP* has improved in all sectors of manufacturing. We also see that production increases while emissions decrease in many sectors, indicating a decoupling of economic growth and environmental degradation. Furthermore, firms' *EP* responds to changes in the CO_2-tax and fossil fuel price, but is more sensitive to the tax, indicating different *EP* behavior among firms depending on why the cost of fossil fuels change. Several sectors also display a positive tendency over time in *EP*, which may suggest that *EP* is to some extent stimulated by an overall boost in environmental awareness in society and firms.

Keywords: CO_2 emissions, CO_2-tax, environmental performance.

JEL codes:

1. Introduction

This study's overall goal is to analyze environmental performance (*EP*) in Swedish manufacturing and explore its potential determinants. Especially, we want to investigate the effectiveness of environmental policy; does environmental policy really work in terms of lowering emissions? Thus, this paper to some extent relates to the discussion concerning decoupling and the Environmental Kuznets Curve (EKC). The term decoupling refers to breaking the link between environmental emissions and economic growth. Decoupling occurs when the growth rate of an environmental pressure is less than the growth rate of its economic driving force (e.g. GDP for a country or output for a firm) over a given period (see for example Diakoulaki and Mandraka, 2007).

As mentioned the analysis presented here is closely related to the decoupling and EKC literature. Concerning decoupling essentially two types of decoupling between CO_2 emissions and economic growth are discussed in the literature: relative and absolute (Azar et al., 2002). Relative decoupling causes emissions to grow at a slower rate than economic growth. Absolute decoupling causes emissions to decline whilst the economy grows. Thus it is clear that absolute decoupling cannot be achieved without relative decoupling. Most decoupling studies, however, are descriptive in its nature in the sense that there are few or no attempts to explain and find the underlying drivers for the path of emissions and economic growth, or the relation between them. Rather they focus how changes in emissions can be decomposed, or attributed, into different factors such as changes in output, energy intensity, industry structure, fuel mix and utility mix (see for example Diakoulaki and Mandaraka, 2007). An exception though is Enevoldsen et al. (2007) who study energy consumption in energy intensive industries in Scandinavia. Their study differs from most of the decoupling literature in the sense that they analyze the drivers behind the development of energy consumption by estimating a factor demand system. They conclude that long-term elasticities for industries are higher than what is normally assumed in Scandinavian energy-sector model, implying that there are opportunities for further decoupling between trends in gross value added, carbon emissions and energy consumption.

Related to the decoupling literature is the EKC literature. The EKC literature (see e.g. Grossman and Kruger, 1995; Selden and Song, 1994; Stern, 2004; Dinda, 2004; Galeotti et al. 2006) differs from the decoupling literature in the sense that EKC studies do not focus decomposition of emissions or energy consumption, but rather the direct connection between economic growth (usually GDP) and emissions. As for the decoupling literature many studies of the EKC are comparative studies based on panel data for countries. There are numerous surveys of the EKC literature (see e.g. Stern et al. 1996, de Bruyn 2000, Dinda, 2004, Stern 2004). Most of these studies reveal mixed results concerning the relationship between growth and emissions. Stern (2004) argues that the mixed results partly is a result of models with what he calls ”very flimsy statistical foundation” and that a new generation efficient frontier models can help disentangle the true relations between growth and the environment. Galeotti et al. (2006) argue in a similar way and propose alternative specifications and functional forms.

Here we contribute to this literature by analyzing the development of environmental performance (*EP*), in terms of CO_2 emissions, in Swedish manufacturing. Measurement of *EP* taking into account explicitly bad outputs is rather sparse in economics research, but more common in the management and operations research literature. Tyteca (1996) reviews attempts to derive indicators of firm level *EP* using linear programming techniques. Zhou et al. (2008) survey data envelopment analyses (DEA) with focus on energy and environmental studies. A few recent examples of assessing *EP* can be found in Färe et al. (2004), Färe et al. (2006), Färe et al. (2010), where a Malmquist-type[2] of index is derived and investigated. In the business/finance literature, *EP* is commonly proxied by ratings produced and compiled by various consulting firms (see e.g. review of corporate social performance studies by Orlitzky and Swanson, 2008). Using subjective ratings as an indicator of *EP* is clearly inferior compared to measuring actual *EP* from company emissions data. In this study, a Malmquist-type of index is derived to evaluate *EP* at firm level for all sectors in Swedish manufacturing during 1990-2004. To our knowledge, no other studies have provided industry-wide evidence of *EP* for a country over such a long time. The analysis gives important insights into the overall *EP* in

[2] See Malmquist, 1953, or Färe and Grosskopf, 2003.

Swedish industry and what sectors are leading and who are lagging behind in terms of sustainable development.

Furthermore, we explore the relationship between the actual *EP* of firms and one aspect of Swedish environmental policy, that is, the CO_2-tax. Since Sweden was the first country to introduce a specific and explicit CO_2-tax in 1991 we believe that Sweden may serve as a test bench for the effectiveness of environmental taxation in general. By international comparisons, the tax rate was set at a relative high level, and has increased in real terms since then. This together with the fact that we can measure the actual tax that firms pay makes the Swedish case suitable for an analysis of this kind. To achieve our objective we make use of a panel data set of firm level data for the Swedish manufacturing industry covering the period 1990 to 2004. The empirical analysis can be viewed as analysis in two steps. In the first step we define and calculate an *EP* index based as ratios of Shepard-type output distance functions. This exercise in itself will provide new and important results on sustainable development in Swedish industry. In the second step we use this index as an independent variable in a regression analysis where the CO_2-tax facing each firm is the key independent variable.

The rest of the paper is structured as follows: In section 2 we offer a comprehensive description of the development of the CO_2-tax in Sweden and how it is structured; section 3 provides the theoretical basis for the *EP* index that we will construct; sections 4-6 presents the empirical approach, the data, and the results; a discussion and some concluding remarks are given in section 7.

2. The Swedish CO_2-tax

In connection with the oil crises in the 1970s the reasons for taxation in Sweden were extended to explicitly incorporate the energy perspective (Brännlund, 2009, pp. 204). A tax policy was introduced that intended to reduce oil consumption, and this strategy was combined with expanding the capacity of nuclear power for electricity production. During the 1980s the arguments for taxation of energy shifted somewhat towards environmental concerns. In 1986, for example, the tax on gasoline was differentiated to distinguish between leaded and unleaded gasoline. This turned out to be very effective since leaded gasoline was phased out in a few years. In the beginning of the 1990s a major tax reform was implemented in Sweden. The reform covered the whole tax system in Sweden, including energy and environmental taxes. The reform further strengthened the difference between energy taxes and so-called environmental taxes, by incorporating, among other things, the introduction of explicit taxes on sulfur (S) and carbon dioxide (CO_2). In the subsequent energy tax reform in 1993 the energy and the CO_2-tax rates were substantially increased, however, with the exception for the manufacturing sector that was exempted from the energy tax, and only taxed at 25 percent of the CO_2-tax.

Figure 1 displays the historical development of the CO_2-tax rate in Sweden for both the industry and non-industry sectors. At first glance Figure 1 reveals that there is a positive trend in the CO_2-tax rate. The CO_2-tax was introduced in the beginning of 1991 and, as is shown in the figure, the non-industry tax rate has more than tripled from the introduction to present time. It also appears that, starting with the 1993 energy tax reform, the tax burden has continuously shifted from the industry sector to the non-industry sector. Consequently, if there is a link between taxation and contribution to reduction in CO_2 emissions, it should mainly be attributed to the non-industry sector. The main reason for the Swedish industry being exempted from a relative large part of the CO_2-tax is due to competitiveness and carbon leakage concerns, i.e., the Swedish tax policy cannot deviate too much from tax policies in other countries (Brännlund, 2009, p. 206).

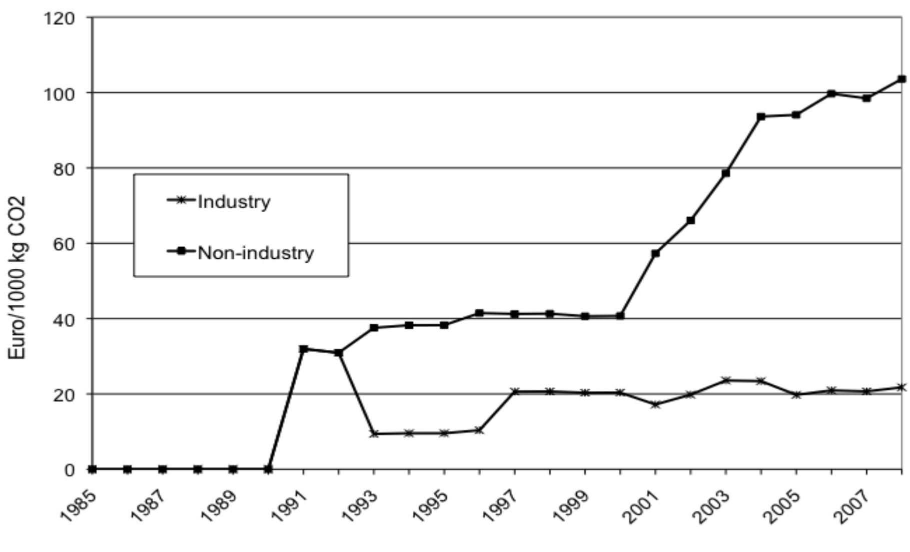

Figure 1. CO_2-tax 1991 to 2008. EURO/ton of carbon dioxide at 2009 prices. Source: Swedish National Tax Board (Riksskatteverket; www.skatteverket.se).

Presently, the general CO_2-tax rate is 1.05 SEK per kg CO_2 (€ 110 per ton). However, as discussed, the industry sector in Sweden has been, and is, largely excluded from the CO_2-tax. The 1993 energy tax reform introduced special regulations relieving the tax burden on the manufacturing industry. This special treatment has been strengthened ever since, as shown in Figure 1. Currently the manufacturing, agriculture, and forestry sector have to pay 21 percent of the general tax rate on CO_2. For firms within these sectors that have a tax bill for fossil fuels amounting to at least 0.5% of value added there is an opportunity to apply for tax refunds. However, the remaining amount of tax paid must be at least 0.5 percent of the value of produced goods. Additionally, to address specifically energy intensive manufacturing firms; if the total amount tax paid exceeds 0.8 percent of the value of produced goods the manufacturer may apply for further tax reductions. In this case maximally 24 percent of the tax amount that exceeds 0.8 percent of the sales value has to be paid.

Given all these exemptions and special rules it can be concluded that the tax system is rather complicated and not very transparent. Although there is a uniform CO_2-tax rate, the actual, or effective, tax rate will vary considerably between firms, both within and between sectors. More on this in the data section below.

3. Theoretical background to measuring environmental performance

The theoretical approach follows primarily Färe et al. (2006).[3] The basic idea is that the components of *EP* index are quantity indexes that, in our case, are constructed as ratios of Shephard-type output distance functions. The underlying idea is that distance functions are regarded as aggregator functions, i.e., they can be used to aggregate pollutants, which make them suitable as building blocks for the construction of *EP* indexes. Such an index then forms a simple but attractive measure on *EP* by measuring how much is produced per unit of emitted pollutants.

[3] For a background and more in depth discussion, see Färe and Primont (1995), Färe and Grosskopf (2003), and Färe et al. (2004).

3.1 The production technology

Underlying the *EP* index is neoclassical production theory. However, prior to the theoretical outline, some notations are needed. Let the vector $y = (y_1,...,y_M) \in \Re_+^M$ be market goods, or good outputs, and $b = (b_1,...,b_J) \in \Re_+^J$ be pollutants, or bad outputs. In the production of good and bad outputs inputs are used, denoted by the vector $x = (x_1,...,x_N) \in \Re_+^N$. Accordingly, firm technology can be expressed by the output possibility set as $P(x) = \{(y,b) : x \text{ can produce}(y,b)\}$, and it is assumed to be convex, closed, and bounded, i.e., compact, with inputs and good outputs being freely disposable. Good outputs being freely disposable is formally expressed as $(y,b) \in P(x)$ and $y' \leq y$ then $(y',b) \in P(x)$, and is interpreted as that a good output can always be reduced without reducing any other output.

In addition to these technological properties, shaping the frontier of $P(x)$, further properties must be introduced to distinguish good outputs from bad outputs. Firstly, good and bad outputs are assumed to be weakly disposable. For good outputs this follows from the assumption of being freely disposable, which is sufficient for being weakly disposable. For bad outputs we assume that they are only weakly disposable. This means that good and bad outputs can always be simultaneously reduced proportionally, i.e.:

$$\text{if } (y,b) \in P(x) \text{ and } 0 \leq \theta \leq 1 \text{ then } (\theta y, \theta b) \in P(x). \tag{1}$$

Bad outputs being only weakly disposable then states that a reduction in a bad output, or emissions, cannot be accomplished without giving up some good output directly or indirectly; directly by reducing production, indirectly by reallocating resources from the production of good output to the bad output cleaning process (Färe et al., 2006, p. 261).

A second technological property, imposed to distinguish good outputs from bad outputs, is that (y,u) is null-joint, that is:

$$\text{if } (y,b) \in P(x) \text{ and } b = 0 \text{ then } y = 0, \tag{2}$$

which states that good output cannot be produced without producing any bad output, i.e., bad output is here modeled as a by-product.

3.2 Environmental performance index

To assess firms' *EP* in production, we adopt a quantity approach basically made up of ratios of output distance functions. These functions are here defined on the output possibility set, *P(x)*, described above, and therefore the functions inherit the underlying technological properties. In order to first form a good output quantity index, Shephard output distance functions are defined for the good output sub-vector between time periods *t* and *t+1* as follows (Färe et al., 2006, p. 261):[4]

$$D_y^t\left(x^o, y^t, b^o\right) = \min\left\{\theta : \left(\frac{y^t}{\theta}, b^o\right) \in P^t\left(x^o\right)\right\}$$

and (3)

$$D_y^t\left(x^o, y^{t+1}, b^o\right) = \min\left\{\theta : \left(\frac{y^{t+1}}{\theta}, b^o\right) \in P^t\left(x^o\right)\right\},$$

of which the solutions, θ^*, gives the maximum feasible proportional expansion of good outputs, given inputs, bad outputs and technology. As such, $D_y^t(\cdot) = \theta^*$, reflects technical efficiency in production by measuring the distance between the actual production level and the best practice production level. By the definitions in equation (3), the good output sub-vector distance function is homogeneous of degree +1 in good output, y.

Then, by letting x^o and b^o be given reference levels of inputs and bad outputs, respectively, a good output quantity index is specified for the output vectors y^t and y^{t+1} as follows:

[4] Regarding the Shephard output distance function, Färe et al. (2006) refer to Shephard, R.W. (1970) *Theory of Cost and Production Functions*. Princeton University Press, Princeton.

$$Q_y^t\left(x^o,b^o,y^{t+1},y^t\right)=\frac{D_y^t\left(x^o,y^{t+1},b^o\right)}{D_y^t\left(x^o,y^t,b^o\right)} \quad , \tag{4}$$

which reflects the change in good output production from period t to period $t+1$, everything else constant. Specifically, if $y^{t+1} > y^t$ then $Q_y^t > 1$, as the distance function is increasing in y. The quantity index in equation (4) satisfies some Fisher tests including homogeneity in output, being time-reversal, transitivity, and dimensionality.[5] In the general case, including multiple good and bad outputs, all these conditions and the quantity index in equation (4) depend on the reference vector, (x^o,b^o) (Färe and Grosskopf, 2003, p. 57). However, in this paper we study the special case of a single good and bad output technology, which means independency of (x^o,b^o).

The quantity index being independent of (x^o,b^o) in the single good and bad output case follows from the distance function being homogenous of degree +1 in good outputs, y. From the first expression in equation (3), the homogeneity property may be stated as:

$$D_y^t(x^o,\lambda y^t,b^o)=\lambda D_y^t(x^o,y^t,b^o)$$

Setting $\lambda = 1/y^t$ gives:

$$D_y^t(x^o,1,b^o)\cdot y^t = D_y^t(x^o,y^t,b^o)$$

Similarly, for the second expression in equation (3) we get:

$$D_y^t(x^o,1,b^o)\cdot y^{t+1} = D_y^t(x^o,y^{t+1},b^o)$$

Hence, the good output quantity index in equation (4) may be rewritten as:

$$Q_y^t\left(y^{t+1},y^t\right)=\frac{D_y^t\left(x^o,1,b^o\right)\cdot y^{t+1}}{D_y^t\left(x^o,1,b^o\right)\cdot y^t}=\frac{y^{t+1}}{y^t} \tag{4}$$

[5] Färe and Grosskopf (2003) refer to Fisher (1922): *The Making of Index Numbers*. Boston: Houghton Mifflin.

By following the same procedure as above for bad outputs, starting with the distance functions defined for the bad output sub-vector between time periods t and $t+1$, and contracting bad outputs, we arrive at the following bad output quantity index:

$$Q_b^t\left(b^{t+1}, b^t\right) = \frac{D_b^t\left(x^o, y^o, 1\right) \cdot b^{t+1}}{D_b^t\left(x^o, y^o, 1\right) \cdot b^t} = \frac{b^{t+1}}{b^t}, \tag{5}$$

which reflects the change in bad output from period t to period $t+1$, holding inputs and good output constant. Specifically, if $b^{t+1} < b^t$ then $Q_b^t < 1$.

Finally, we can specify the *EP* index as:

$$EP^{t,t+1}\left(y^{t+1}, y^t, b^{t+1}, b^t\right) = \frac{Q_y^t\left(y^{t+1}, y^t\right)}{Q_b^t\left(b^{t+1}, b^t\right)} = \frac{y^{t+1}/y^t}{b^{t+1}/b^t} = \frac{y^{t+1}/b^{t+1}}{y^t/b^t}, \tag{6}$$

which credits firms that adopt a production process that produce more good output per unit bad output. Clearly, if production of good output increases between the time periods t and $t+1$, everything else constant, it will influence $EP^{t,t+1}(\cdot)$ positively. On the other hand, if bad output increases, holding good output constant, it will influence $EP^{t,t+1}(\cdot)$ negatively. Hence, a firm with a relatively clean production process, or a relative high production of the good output, will have a relatively high *EP* score.

Furthermore, we will also study environmental performance at the industrial level. However, for that we need an index that aggregates firm performance over firms, measured in equation (6), to industrial performance. As shown in Färe et al. (2006), environmental performance in industry j, $EP_j^{t,t+1}\left(y_j^{t+1}, y_j^t, b_j^{t+1}, b_j^t\right)$, is defined as geometric means of $i = 1,...,I$ firms' performance in that industry, i.e.,:

$$\left(\prod_{i=1}^I \frac{y_{i,j}^{t+1}/b_{i,j}^{t+1}}{y_{i,j}^t/b_{i,j}^t}\right)^{1/I} = \frac{\left(\prod_{i=1}^I y_{i,j}^{t+1}\right)^{1/I} / \left(\prod_{i=1}^I y_{i,j}^t\right)^{1/I}}{\left(\prod_{i=1}^I b_{i,j}^{t+1}\right)^{1/I} / \left(\prod_{i=1}^I b_{i,j}^t\right)^{1/I}} = \frac{\left(\prod_{i=1}^I y_{i,j}^{t+1}\right)^{1/I} / \left(\prod_{i=1}^I b_{i,j}^{t+1}\right)^{1/I}}{\left(\prod_{i=1}^I y_{i,j}^t\right)^{1/I} / \left(\prod_{i=1}^I b_{i,j}^t\right)^{1/I}}. \tag{7}$$

An interesting conclusion drawn from the expressions in equations (6) and (7) is that *EP* not only can be measured, but also can be divided, or decomposed, into two components.

For instance, if an industry's *EP* improves it can be investigated whether it is mainly due to an increase in good output or mainly due to a reduction in bad output, or due to a balanced combination of the two (Färe and Grosskopf, 2003, p. 58). This also provides us with a measure on decoupling. In fact, we will be able to find out whether decoupling is relative or absolute.

4. Empirical approach

The empirical analysis is performed in two steps. First, following the theoretical foundation outlined in the previous section, we specify and calculate an *EP* index at firm level and different levels of aggregation. Second, we analyze potential drivers of the *EP* using a panel data estimation approach. *EP* is here defined as intertemporal changes in carbon dioxide intensity in Swedish manufacturing.

According to equation (6), an empirical *EP* index for a single good output (production output; *y*) and a single bad output (carbon dioxide emissions; CO_2) technology for firm *i* in sector *j* between time period *t* and *t+1* can be formulated as:

$$EP_{i,j}^{t,t+1} = \frac{y_{i,j}^{t+1} / CO2_{i,j}^{t+1}}{y_{i,j}^{t} / CO2_{i,j}^{t}} . j = sector,\ i = firm \qquad (8)$$

A positive (negative) change in *EP* means that CO_2 intensity or emissions per output unit has decreased (increased) between time period *t* and *t+1*. This is the index we calculate and base our empirical analysis on. When needed, the index is aggregated to sector and whole industry levels according to (7).

One of our aims is to assess what factors that primarily have affected *EP* in different sectors and over time. Our hypothesis is that the firms' *EP* has been affected primarily by changes in the cost of using fossil fuels and emissions; that is, the change in the CO_2-tax, and the change in the price of fossil fuel. Furthermore, a plausible hypothesis is that there is a substantial heterogeneity in how firms' are affected by changes in prices and taxes. Firms with a large fuel cost share may have less potential to improve their *EP* due to technological constraints which make it hard to substitute - to a large extent - fuel as an input in production. However, it may also be the case that more fuel intensive firms/sectors are more motivated to cut emissions because there are significant cost savings to be achieved by increasing *EP*. For this reason we include the cost share for fossil fuels as an explanatory variable. Furthermore, we include a variable that reflects capital intensity in our empirical specification. One could argue that capital intensive firms have more difficulties to decrease its environmental impact due to the substantial energy amounts that are needed to propel a large machine park. On the other hand, firms and sectors with high capital intensity may be more motivated to save energy and invest relatively more in "green" and energy saving technology, and thus improve *EP* relative to less capital intensive firms and sectors. How fuel and capital intensity affect *EP* is ultimately an empirical question. Finally, the size of a firm, technological progress, and overall environmental awareness and societal pressure, is assumed to potentially impact *EP*. How size affects *EP* is not obvious, but technological progress and environmental awareness/pressure are likely to be of positive impact. Size is measured as size dummy (four classes) generated from number of employees, and technological progress and environmental awareness/pressure are simply proxied by a time trend variable.

To sum up the empirical model considerations; it is assumed that *EP* - in terms of our specified carbon intensity index in (8) - is governed by changes in the CO_2-tax (τ), changes in price of fossil fuels (*pf*), controlling for cost share of fossil fuels at t (*sfuel*), capital intensity at t (capital stock over total employees, *kapin*), a size effect measured at t (*size*), and finally a general time-trend (*trend*), possibly non-linear, that captures technological progress and increased environmental awareness/pressure on firms during the time period studied. The general form of this relationship we write:

$$EP_{i,j}^{t,t+1} = f\left[(\tau_{i,j}^{t+1} - \tau_{i,j}^{t}), (pf_{i,j}^{t+1} - pf_{i,j}^{t}), \mathbf{X}_{i,j}^{t} \right], \tag{9}$$

where $\mathbf{X}_{i,j}^{t} = [sfuel_{i,j}^{t}, kapin_{i,j}^{t}, size_{i,j}^{t}, trend]$, i.e., a vector of control variables. The hypotheses about the partial responses of *EP* with respect to changes in the determinants are summarized as follows;

$$\frac{\partial EP_{i,j}^{t,t+1}}{\partial(\tau_{i,j}^{t+1}-\tau_{i,j}^{t})}>0,\ \frac{\partial EP_{i,j}^{t,t+1}}{\partial(pf_{i,j}^{t+1}-pf_{i,j}^{t})}>0,$$
$$\frac{\partial EP_{i,j}^{t,t+1}}{\partial sfuel_{i,j}^{t}}\neq 0,\ \frac{\partial EP_{i,j}^{t,t+1}}{\partial kapin_{i,j}^{t}}\neq 0,\ \frac{\partial EP_{i,j}^{t,t+1}}{\partial size_{i,j}^{t}}\neq 0,\ \frac{\partial EP_{i,j}^{t,t+1}}{\partial trend^{t}}>0. \tag{10}$$

In the empirical estimation of (9) we assume a log-linear Cobb-Douglas-type of function:

$$\log(EP_{i,j}^{t,t+1})=c_{i,j}+a_{1,j}\log(\Delta\tau_{i,j}^{t+1})+a_{2,j}\log(\Delta pf_{i,j}^{t+1})+a_{3,j}\log(sfuel_{i,j}^{t})+a_{4,j}\log(kapin_{i,j}^{t})$$
$$\sum_{size=1}^{4-1}a_{5size,j}size_{i,j}^{t}+a_{6,j}trend^{t}+a_{7,j}\left(trend^{t}\right)^{2}+e_{i,j}^{t+1}. \tag{11}$$

This specification allows us to interpret the parameters of interest as elasticities. Equation (10) is estimated with panel data methods, with both fixed effects (FE) and random effects (RE). This means that $c_{i,j}$ is either a firm specific constant (FE), or that the intercepts $c_{i,j}$ are drawn from a common distribution with mean c_j and variance v_{cj} (RE). We also compare these panel methods with a simple pooled OLS, but results from this will be suppressed unless they are of importance. We test for significance of the FE model with an F-test to check whether a model with individual intercepts is significantly different from a model with a common intercept. A Hausman test is performed to check difference between FE and RE estimates. We only report and discuss parameter estimates of the most relevant model. The error term $e_{i,j}^{t+1}$ is heteroskedastic-consistent white noise.

5. Data

The raw data set used in this study is a plant level unbalanced panel covering the years 1990 to 2004 for Swedish manufacturing (SNI10-SNI37).[6] It contains plants with more than five employees and includes, among many other variables, data on output (sales, *y*), capital intensity (capital stock divided by employees, *kapin*) and fuel cost share (*sfuel*), detailed information on emissions of CO_2, and total payment of CO_2-tax for each firm. This enables us to construct a variable for the "effective" CO_2-tax to be used in the analysis, i.e. τ, which is defined as total payment of CO_2-tax divided by total emissions of

[6] This data set has been used in other studies. For a more detailed description of the variables included, see Brännlund and Lundgren (2010) and references therein.

CO_2 in kilos. In constructing the *EP* index we use lagged variables, which then implies that the unbalanced nature of the data set must be handled in some way (gaps and inconsistencies in the data distort the intertemporal index). Here we address this problem by including only those firms that are operating over the whole time span 1990-2004. Given this we can construct a continuous *EP* index over the whole period. There is of course a risk that this procedure gives rise to selection bias in the sense that the firms that have survived over the whole period are not fully representative.

Table 1 below presents the industry classification as well as some relevant descriptive statistics of the balanced sample we use in the empirical analysis.

Table 1. Swedish manufacturing data. Descriptive statistics, mean values 1990-2004 (standard deviation within parenthesis).

Description	NOBS	Output TSEK	CO2 kilos	CO_2-tax SEK/kilo	Price fuel SEK/kwh	Cost share fuel	Capital intensity TSEK
Manufacturing	21030	296502 (745327)	8457 (61011)	0.11 (0.08)	0.35 (0.18)	0.03 (0.05)	1436 (2597)
Mining	193	373993 (681809)	23893 (59174)	0.08 (0.07)	0.28 (0.12)	0.10 (0.08)	2733 (2524)
Food	2056	343003 (362173)	3672 (8531)	0.15 (0.06)	0.29 (0.45)	0.05 (0.05)	1375 (2558)
Textile	403	119323 (116808)	1737 (3403)	0.13 (0.08)	0.34 (0.18)	0.03 (0.05)	1079 (1385)
Wood	1820	191341 (177345)	2312 (11631)	0.04 (0.06)	0.36 (0.18)	0.03 (0.03)	1704 (2162)
Pulp/paper	1292	609754 (731287)	35351 (101467)	0.13 (0.07)	0.24 (0.15)	0.04 (0.05)	1566 (1573)
Printing	959	84040 (117530)	253 (798)	0.06 (0.08)	0.49 (0.21)	0.01 (0.01)	1739 (3144)
Chemical	1021	507796 (1225336)	37242 (149990)	0.12 (0.08)	0.28 (0.19)	0.04 (0.06)	1840 (2929)
Rubber/plastic	947	133501 (165630)	916 (2438)	0.12 (0.08)	0.37 (0.18)	0.03 (0.05)	1120 (1410)
Stone/mineral	1060	110269 (119365)	33154 (168245)	0.14 (0.07)	0.24 (0.13)	0.10 (0.13)	1375 (1688)
Iron/steel	2831	278699 (696952)	6709 (29958)	0.14 (0.07)	0.35 (0.17)	0.03 (0.05)	1593 (5192)

Machinery	2677	209396 (340045)	711 (7187)	0.11 (0.08)	0.39 (0.17)	0.01 (0.02)	1213 (2599)
Electro	1095	391016 (1000759)	390 (754)	0.11 (0.08)	0.41 (0.19)	0.01 (0.01)	1183 (3631)
Motor vehicles	1131	676418 (1941923)	2426 (8977)	0.14 (0.07)	0.34 (0.15)	0.02 (0.03)	957 (1340)

From Table 1 it is obvious that the variation in CO_2-tax rate across and within sectors is rather substantial. The sector tax rate range from 0.04 to 0.15 (SEK/kilo), i.e., the highest rate is more than 3 times the lowest rate. The price paid for fossil fuels also varies across and within sectors, but not as much as the tax. The main reason for this variation is that the mix of fossil fuels varies across and within sectors. Moreover, the cost shares for fossil fuel are generally quite small, ranging from a mere 1% in the Electro, Machinery and Printing industry, to the most fuel intensive sectors Stone/mineral and Mining, which have a 10 % cost share. The most capital-intensive sector by far is Mining, while the other sectors do not stick out as much comparing to the average for Manufacturing.

To further display the variation of the effective tax the box-plot in Figure 2 displays the median and variation of the CO_2 tax for all firms for each year. The height of the box is the difference between the 75th and 25th percentiles, and the horizontal line within each box represents the median. It is clear that the variation between firms is even larger than between sectors. For all years the CO_2 tax ranges from zero to approximately 0.20 SEK/kg.

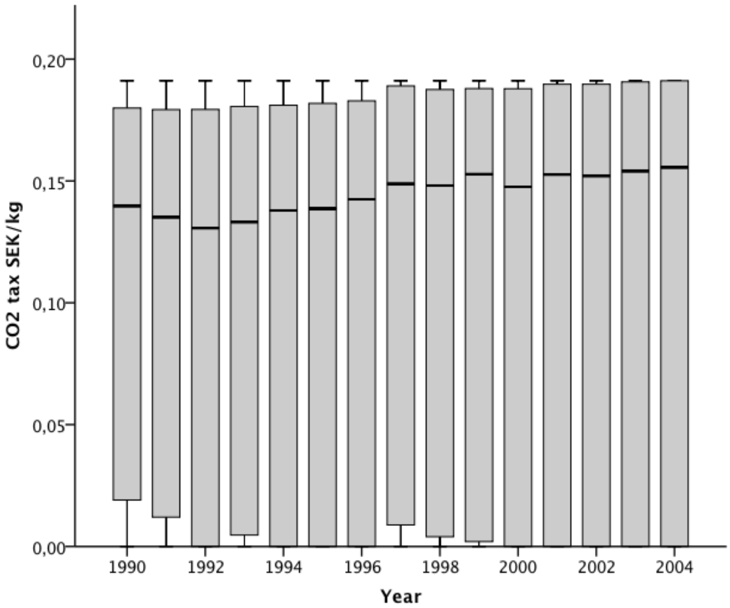

Figure 2. The effective CO2 tax for the Swedish manufacturing industri, SEK/kg

6. Results

First, we present results from the calculation of *EP* according to (8) for sectors and for the manufacturing industry as a whole. Next, we investigate the determinants of *EP* according to (9) by estimating equation (11) sector by sector and for aggregate manufacturing using firm level data.

6.1 Environmental performance: sector and aggregated indexes

The *EP* indexes are calculated at firm level according to (8), and aggregated to sector levels according to (7). A summary of the sector and industry level indexes is presented in figure 3 as mean values for the years 1991 to 2004. The change in CO_2 and production, ΔCO2 and ΔY, are also presented to show the components of *EP*. In the appendix we present tables with year-by-year sector level indexes. Note, however, that in the subsequent econometric analysis, we make use of the non-aggregated firm level indexes as dependent variables.

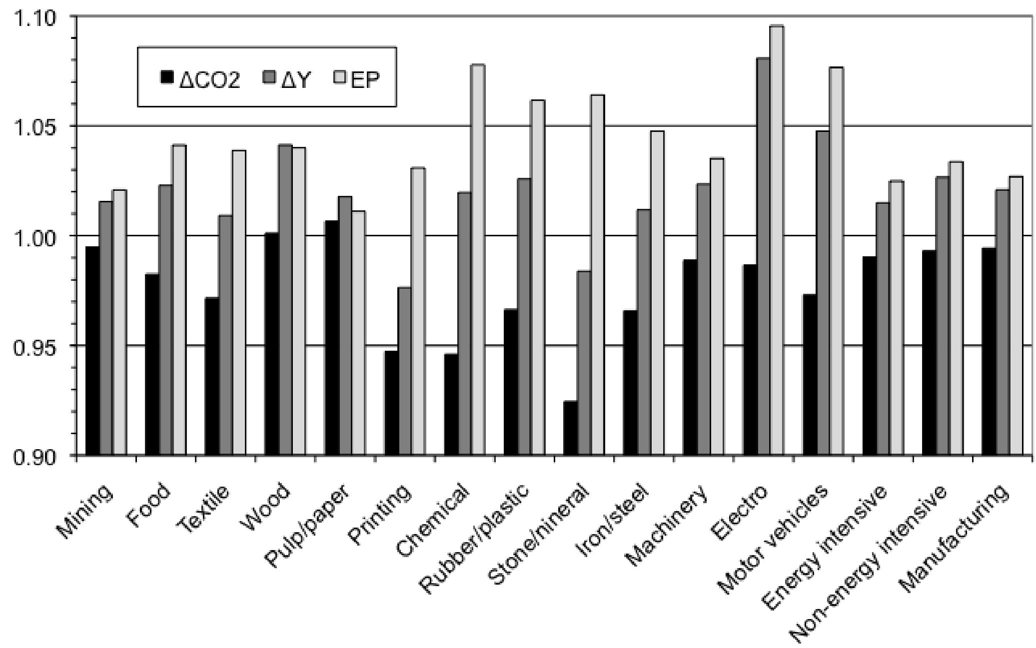

Figure 3. Environmental performance in Swedish industry 1991 to 2004; mean values, sector by sector, and manufacturing as a whole.

Figure 3 show that all sub-sectors, energy and non-energy intensive firms, and the industry as a whole, have improved their *EP* between 1991 and 2004, i.e., *EP* > 1. The sectors Electro, Chemical, and Motor vehicles exhibit the best performance with average growth rates ranging from 7 to 10%, while Pulp/paper only improved *EP* marginally. In figure 3 we also present EP's components, $\Delta CO2$ and ΔY. They indicate that almost all sectors, and other aggregation levels, have experienced falling emissions while at the same time production have been rising, i.e., $\Delta CO2 < 0$ and $\Delta Y > 0$. The only exceptions are Pulp/paper and wood where emissions have increased, but still at slower rate than production. Figure 3 provide convincing evidence of decoupling of production and emissions. See the appendix for a complete presentation of year-to-year *EP* calculations for all sectors.

In figure 4-6 the accumulated *EP* is presented. This is calculated by simply adding the percentage changes over the years 1991-2004: $EP^{1990,1991} + \sum_{t=1991}^{2003} EP^{t,t+1}$. We divide the sample into energy intensive and non-energy intensive sectors and the accumulated *EP* is calculated for each sub-sample.[7] This division reveals some noteworthy differences.

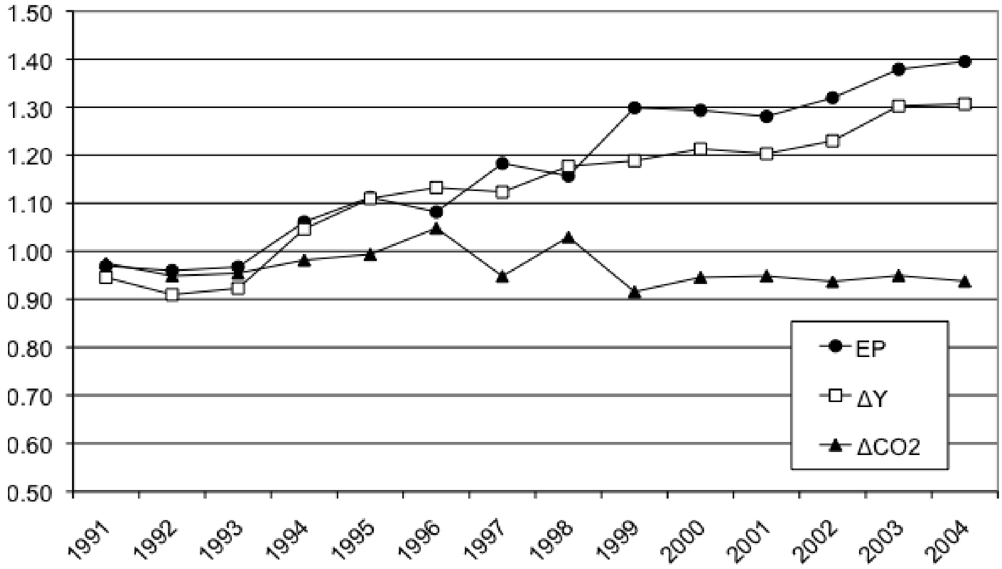

Figure 4. Accumulated environmental performance, Swedish industry.

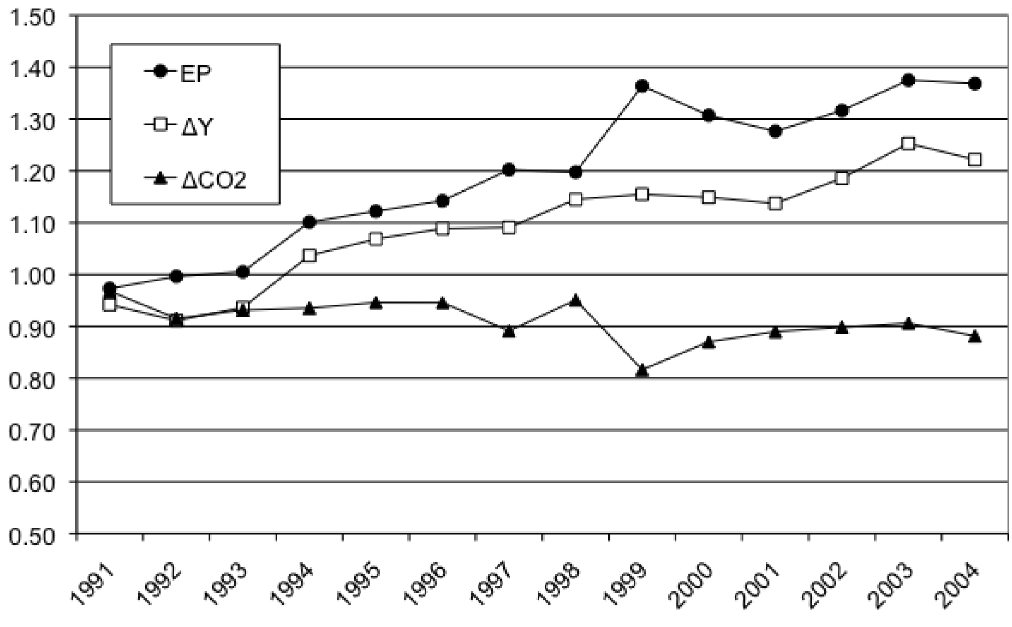

Figure 5. Accumulated environmental performance, energy intensive firms.

[7] Energy intensive firms are defined as being above the average cost share for energy as measured for manufacturing as a whole.

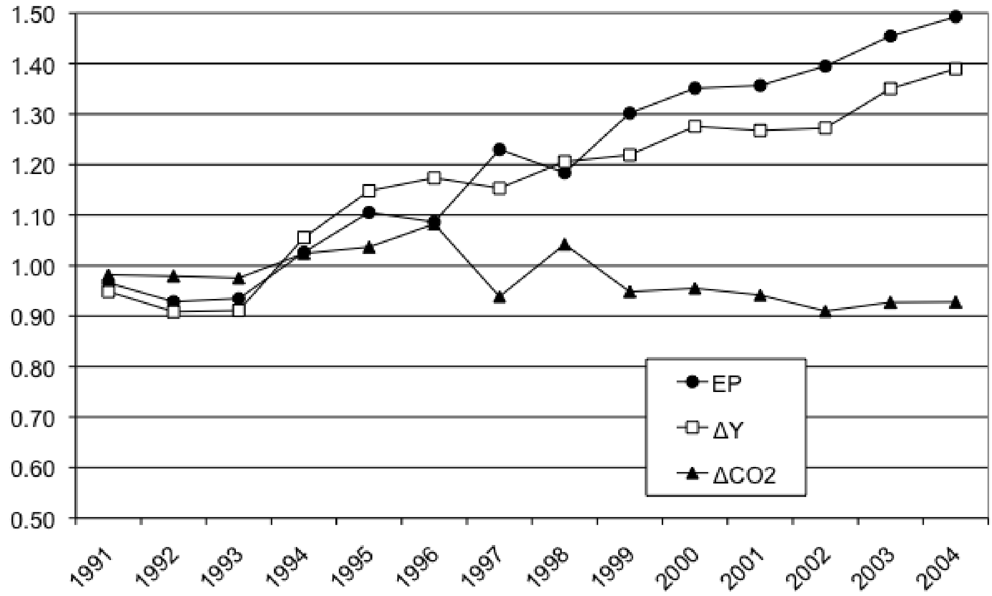

Figure 6. Accumulated environmental performance, non-energy intensive firms.

The industry as a whole have improved its *EP* by about 40%, which is made possible by decreasing emissions by almost 10% and at the same time increasing production by around 30%. Energy intensive and non-energy intensive firms have increased *EP* by about 40 and 50%, respectively. Non-energy intensive firms have a strong linear positive trend in accumulated *EP*, while energy intensive firms' trends are less pronounced and exhibit a somewhat concave shape; i.e., energy intensive firms seem to improve *EP* at a decreasing rate. The reasonable explanation for this difference is that energy intensive firms, due to technological restrictions, have had limited ability to substitute away from fossil fuel intensive energy inputs in the period studied.

6.2 Determinants of environmental performance

Using the firm level *EP* index we derived, equation (11) is estimated for manufacturing as a whole, sector by sector, and for the energy intensive and the non-energy intensive sectors. The results are presented in Table 3 using panel data methods, including both fixed effects (FE) and random effects (RE). The relevance of plain OLS is also checked. The validity of the FE model versus the OLS model is tested with a simple F-test. A Hausman test (Hausman, 1978) is performed to check RE versus FE. In general, RE is more efficient, and should be used over FE. For RE to be preferred it is necessary that the specific (random) effects be orthogonal to the other covariates of the model. The Hausman test is based on the idea that under the hypothesis of no correlation, both FE and RE are consistent, but RE is more efficient. Under the alternative, FE is consistent, but RE is not. That means that under the null, FE and RE should not differ significantly, and a test can be performed on the difference. If they do differ, the Hausman test statistic (chi-squared) is significant, and FE is preferred over RE.

Table 3. Determinants of environmental performance (*EP*). Results for selected parameters and diagnostics from estimating equation (11). (P-values within parenthesis.)

Estimates and diagnostics → Sectors ↓	CO_2-tax	Fuel price	Fuel intensity	Capital intensity	F-test FE vs OLS	Hausman test RE vs FE*	Adj. R^2
Manufacturing	0.475 (0.000)	0.179 (0.000)	0.505 (0.000)	-0.004 (0.852)	2.147 (0.000)	263.4 (0.000)	0.256
Mining	0.045 (0.685)	0.359 (0.001)	0.842 (0.000)	0.473 (0.094)	2.398 (0.014)	19.14 (0.002)	0.399
Food	0.210 (0.026)	0.040 (0.042)	0.464 (0.000)	0.004 (0.910)	1.901 (0.000)	41.06 (0.000)	0.169
Textile	0.768 (0.224)	0.170 (0.014)	0.315 (0.005)	0.114 (0.452)	1.813 (0.020)	28.15 (0.000)	0.143
Wood	0.567 (0.000)	0.348 (0.000)	0.168 (0.000)	0.007 (0.865)	1.0358 (0.402)	12.53 (0.185)	0.437
Pulp/paper	0.306 (0.000)	0.061 (0.041)	0.173 (0.000)	-0.131 (0.115)	0.953 (0.599)	11.31 (0.255)	0.200
Printing	0.044 (0.781)	0.194 (0.000)	0.409 (0.000)	-0.073 (0.345)	1.289 (0.145)	35.76 (0.000)	0.124
Chemical	0.529 (0.066)	0.110 (0.023)	0.526 (0.000)	0.065 (0.517)	4.100 (0.000)	19.49 (0.007)	0.518
Rubber/plastic	0.355 (0.024)	0.147 (0.000)	0.556 (0.000)	0.046 (0.481)	2.492 (0.000)	79.93 (0.000)	0.243
Stone/mineral	0.642 (0.000)	0.193 (0.000)	0.416 (0.000)	-0.051 (0.497)	1.323 (0.049)	73.48 (0.000)	0.273
Iron/steel	0.149 (0.105)	0.155 (0.000)	0.435 (0.000)	-0.032 (0.543)	2.039 (0.000)	563.8 (0.000)	0.192
Machinery	-0.040 (0.545)	0.123 (0.000)	0.396 (0.000)	0.019 (0.701)	1.569 (0.000)	51.86 (0.000)	0.140
Electro	-0.014 (0.903)	0.131 (0.000)	0.413 (0.001)	0.015 (0.864)	2.042 (0.000)	17.04 (0.030)	0.207
Motor vehicles	0.517 (0.007)	0.092 (0.000)	0.292 (0.000)	0.092 (0.071)	1.230 (0.099)	20.69 (0.004)	0.166
Energy intensive	0.458 (0.000)	0.161 (0.000)	0.380 (0.000)	-0.045 (0.183)	1.721 (0.000)	117.8 (0.000)	0.283
Non-energy intensive	0.244 (0.000)	0.100 (0.000)	0.355 (0.000)	0.024 (0.350)	1.671 (0.000)	216.1 (0.000)	0.135

* If the P-value for the Hausman test is lower than 0.05, the fixed effects model is selected.

Table 3 show that *EP* in manufacturing as a whole is sensitive to both tax changes and fuel price changes (elasticities are 0.475 and 0.179, respectively). From the standard errors displayed in the appendix it can be shown, however, that *EP* is significantly more sensitive to the tax. Fuel intensity also seem important for the development of *EP*; the higher the fuel intensity, the more positive growth in *EP*, possibly because firms with substantial fuel use also have the most to gain from improving energy/fuel efficiency and thus *EP*. Capital intensity has a negative sign, but is not statistically significant.[8] Sector results show similar pattern as aggregate results, however in some cases the CO_2-tax is not statistically significant (Mining, Textile, Printing, Iron/steel, Machinery, Electro). Fuel price has a significant positive influence on *EP* across all sectors, as one would expect. In the sectors where the CO_2-tax is a statistically significant determinant of *EP*, it "dominates" the fuel price effect. This would suggest there is a type of signaling effect of the tax; an increase in the tax may be perceived as long-term and the firms adopt accordingly, while fuel price changes are perceived as more uncertain, and the response is comparatively moderate. In all sectors, high fuel intensity means better *EP*, corroborating the result at aggregate manufacturing level. Again, this is probably because the firms with high fuel usage have the most to gain financially from lowering fuel consumption and emissions. The effect on *EP* of capital intensity is statistically significant (at 10% level) only in Mining and Motor vehicles, suggesting that capital per worker is not very important as a determinant for *EP*. Finally, looking at results for energy intensive and non-energy intensive firms, we see that the general pattern mimics the results of other aggregate levels, i.e., manufacturing as a whole and the specific sectors. It is clear, however, that energy intensive firms are almost twice as responsive to the tax compared to non-energy intensive firms (elasticities are 0.458 and 0.244, respectively), indicating that firms with high energy and fuel usage are relatively more prone to respond to a change in tax payment. Table A2 in the Appendix show a few more results. The size effect is positive, suggesting that bigger firms show relatively better *EP*, but this result is only statistically significant in some sectors. The time trend effect is generally positive with either concave or convex shape, but not statistically significant in

[8] We checked for multicollinearity of fuel and capital intensity, but the correlation coefficient was small and statistically insignificant.

all sectors. One interpretation of this result is that improvements in *EP* is in part stimulated by a trend-like increase in overall environmental awareness and sustainability thinking among firms and in society during the period studied.

In sum; firms' *EP* respond to changes in the CO_2-tax and fuel price, but are more sensitive to the tax. High fuel intensity seems to increase *EP*, while high capital intensity has no or modest effect. Firm size is positively related to *EP*, but this is not a universal result. Many sectors also display a positive trend in *EP* during the period studied.

7. Concluding remarks

The results of our analysis are in line with e.g. Shadbegian and Gray (2006), and Färe et al. (2006), who study *EP* in traditional smoke-stack industries and power plants in the US. That is, *EP* is positively affected by environmental policy. This result is also to some extent supported by Enevoldsen et al. (2007) who find evidence that energy taxes and especially CO_2 taxes are important instruments for decoupling of economic growth and CO_2 emissions. They generate their results by estimating a factor demand model based on a panel of aggregate sectoral data for the Scandinavian industry. Our contribution, compared to Enevoldsen et al. (2007) is; (1) that we explicitly derive an environmental performance index, which then can be used directly in a regression analysis; (2) we use micro-data on firm level which allows us to take heterogeneity within sectors into account.

Our results clearly reveals a fairly strong increase in environmental performance over the period 1991-2004 in all industrial sectors, Furthermore, the results reveals that almost all sectors have experienced falling emissions while at the same time production have been rising, i.e. absolute decoupling between production and emissions of CO_2. The only exceptions are Pulp/paper and Wood industry, which shows relative decoupling in the sense that emissions have increased, but at slower rate than the increase in production.

Concerning the determinants of environmental performance the conclusion is that the price of fossil fuels and the actual CO_2 tax have contributed significantly in the sense that a higher price and/or a higher tax affects environmental performance positively. Thus one can say that the CO_2 tax that was introduced in 1991 has been an important instrument in lowering CO_2 emissions. The results also provides some very interesting results concerning potential differences in effect depending on whether a higher fossil fuel price faced by the firm is due to higher producer price of fossil fuels, or due to a higher CO_2 tax. For the manufacturing as a whole the results indicates that there is a significance difference in effect, in the sense that environmental performance is more sensitive to a change in the tax than to a change in the producer price. On a more disaggregated level the results are slightly more mixed and the differences are not always significant. One possible explanation to this is that the tax has a signaling effect in that the introduction of the CO_2 tax provides new information about the properties of the directly taxed goods (see for example Ghalwash, 2007). This may then have more permanent effects on the production technology and input choice.

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Appendix A

Table A1. Year-by-year calculation of *EP* and its components between 1991 and 2004; mean values at sector and industry levels.

	Mining			**Food**			**Textile**		
Year	ΔCO2	ΔY	EP	ΔCO2	ΔY	EP	ΔCO2	ΔY	EP
1991	0.984	0.940	0.956	1.009	1.013	1.004	0.904	0.936	1.036
1992	1.006	0.910	0.904	0.994	1.029	1.034	1.105	0.978	0.885
1993	0.832	0.983	1.181	0.973	1.028	1.056	0.903	0.976	1.080
1994	1.009	1.017	1.008	1.062	1.056	0.995	1.106	1.112	1.006
1995	1.146	1.141	0.996	1.074	1.073	0.999	0.874	1.033	1.182
1996	1.157	1.178	1.018	1.031	0.996	0.967	1.097	0.998	0.910
1997	0.982	0.861	0.877	0.888	0.926	1.043	0.920	0.970	1.054
1998	1.192	1.116	0.937	0.763	1.012	1.325	1.062	0.982	0.924
1999	0.587	0.958	1.633	0.918	1.012	1.102	0.972	1.005	1.034
2000	1.238	1.047	0.846	1.088	1.048	0.963	0.860	0.987	1.147
2001	0.886	0.916	1.033	0.980	0.962	0.982	1.038	1.055	1.017
2002	1.009	1.010	1.001	0.975	0.999	1.025	0.897	1.066	1.189
2003	1.083	1.186	1.095	1.066	1.137	1.067	0.958	1.070	1.117
2004	1.024	1.022	0.999	0.985	1.046	1.062	0.958	0.976	1.019
Geo-mean	0.995	1.016	1.021	0.982	1.023	1.041	0.972	1.009	1.039

	Wood			**Pulp/paper**			**Printing**		
Year	ΔCO2	ΔY	EP	ΔCO2	ΔY	EP	ΔCO2	ΔY	EP
1991	0.932	0.951	1.020	1.016	0.983	0.968	1.040	0.949	0.912
1992	0.966	0.959	0.993	0.983	1.029	1.047	1.036	0.906	0.874
1993	1.020	1.068	1.048	1.094	1.047	0.957	0.932	1.023	1.098
1994	0.991	1.113	1.123	1.013	1.101	1.086	0.973	0.987	1.015
1995	1.020	1.098	1.076	1.022	0.952	0.932	0.938	0.970	1.033
1996	1.028	1.018	0.990	1.093	1.005	0.919	0.995	1.030	1.035
1997	1.046	1.077	1.030	0.961	1.026	1.067	0.785	0.925	1.179
1998	1.007	1.034	1.027	1.042	1.002	0.962	0.995	1.050	1.056
1999	0.903	1.046	1.158	0.859	1.027	1.195	0.820	0.995	1.213
2000	1.026	1.027	1.001	1.054	1.022	0.970	1.012	0.970	0.958
2001	1.004	1.046	1.041	1.020	0.952	0.933	0.897	0.937	1.044
2002	1.030	1.049	1.019	1.047	1.042	0.996	0.955	1.032	1.081
2003	1.017	1.109	1.091	0.975	1.051	1.078	0.980	0.913	0.932
2004	1.037	0.999	0.963	0.940	1.021	1.086	0.942	0.997	1.059
Geo-mean	1.001	1.041	1.040	1.007	1.018	1.011	0.947	0.976	1.031

	Chemical			Rubber/plastic			Stone/mineral		
Year	ΔCO2	ΔY	EP	ΔCO2	ΔY	EP	ΔCO2	ΔY	EP
1991	1.044	1.029	0.987	0.966	0.937	0.971	0.965	0.923	0.957
1992	0.894	1.021	1.143	0.941	0.998	1.061	0.781	0.866	1.108
1993	0.948	1.008	1.064	0.903	1.039	1.151	0.872	0.934	1.071
1994	1.103	1.111	1.007	0.940	1.119	1.190	0.982	0.995	1.013
1995	0.907	0.991	1.092	1.029	1.037	1.008	1.009	0.970	0.961
1996	1.135	0.939	0.828	1.043	0.985	0.944	0.855	0.986	1.153
1997	0.968	0.997	1.030	1.005	1.083	1.078	0.910	0.960	1.055
1998	1.043	1.055	1.011	1.080	1.075	0.995	0.958	1.036	1.081
1999	0.707	0.918	1.298	0.901	1.009	1.120	0.699	1.005	1.437
2000	0.719	0.879	1.223	0.754	1.022	1.355	1.051	1.013	0.964
2001	0.849	1.016	1.197	1.081	0.997	0.922	1.027	1.011	0.984
2002	1.003	1.106	1.102	0.962	1.038	1.079	1.001	0.983	0.982
2003	1.069	1.211	1.134	1.028	1.021	0.993	0.920	1.075	1.169
2004	0.980	1.036	1.057	0.947	1.014	1.071	0.987	1.034	1.047
Geo-mean	0.946	1.020	1.078	0.966	1.026	1.062	0.925	0.984	1.064

	Iron/steel			Machinery			Electro		
Year	ΔCO2	ΔY	EP	ΔCO2	ΔY	EP	ΔCO2	ΔY	EP
1991	0.903	0.900	0.997	0.950	0.874	0.920	0.966	0.984	1.018
1992	0.927	0.973	1.050	0.943	0.902	0.956	0.949	1.046	1.102
1993	0.974	1.025	1.052	0.996	1.014	1.018	1.089	1.015	0.932
1994	0.977	1.131	1.158	1.083	1.205	1.113	1.023	1.215	1.188
1995	0.962	1.057	1.099	1.011	1.126	1.114	0.942	1.128	1.197
1996	1.035	1.068	1.031	1.029	1.044	1.015	1.116	1.056	0.946
1997	0.875	1.016	1.162	0.839	0.976	1.163	0.799	1.076	1.347
1998	1.070	1.080	1.010	1.091	1.044	0.957	1.140	1.084	0.951
1999	0.891	1.026	1.151	0.908	0.964	1.062	0.959	1.100	1.148
2000	1.015	0.994	0.979	1.019	1.063	1.044	0.981	1.158	1.181
2001	1.019	0.959	0.941	0.968	1.004	1.037	1.102	1.148	1.041
2002	0.994	1.065	1.072	0.967	1.005	1.039	0.910	0.956	1.050
2003	0.974	1.015	1.042	1.039	1.097	1.056	0.926	1.102	1.190
2004	0.930	0.887	0.954	1.032	1.058	1.026	0.969	1.093	1.127
Geo-mean	0.966	1.012	1.048	0.989	1.024	1.035	0.987	1.081	1.095

	Motor vehicles		
Year	ΔCO2	ΔY	EP
1991	0.895	0.919	1.027
1992	1.006	0.925	0.919
1993	0.986	0.905	0.919
1994	1.064	1.309	1.231
1995	1.036	1.262	1.219
1996	1.077	1.019	0.946
1997	0.881	1.021	1.159
1998	1.004	1.098	1.093
1999	0.844	1.045	1.238
2000	0.968	1.129	1.167
2001	0.956	0.906	0.947
2002	0.955	1.047	1.096
2003	1.012	1.132	1.119
2004	0.968	1.042	1.076
Geo-mean	0.973	1.048	1.077

	Energy intensive			Non-energy intensive			Manufacturing		
Year	ΔCO2	ΔY	EP	ΔCO2	ΔY	EP	ΔCO2	ΔY	EP
1991	0.968	0.942	0.973	0.982	0.948	0.966	0.975	0.945	0.969
1992	0.947	0.969	1.023	0.997	0.960	0.962	0.974	0.964	0.990
1993	1.016	1.025	1.009	0.996	1.002	1.006	1.006	1.013	1.008
1994	1.004	1.100	1.096	1.049	1.145	1.092	1.027	1.124	1.094
1995	1.011	1.032	1.021	1.013	1.093	1.079	1.012	1.063	1.051
1996	1.000	1.020	1.020	1.046	1.026	0.981	1.055	1.023	0.970
1997	0.946	1.002	1.060	0.857	0.980	1.144	0.900	0.991	1.101
1998	1.059	1.054	0.995	1.103	1.052	0.954	1.082	1.053	0.974
1999	0.866	1.010	1.166	0.906	1.013	1.118	0.886	1.012	1.142
2000	1.054	0.994	0.943	1.007	1.057	1.049	1.030	1.025	0.995
2001	1.019	0.988	0.969	0.986	0.992	1.006	1.003	0.990	0.987
2002	1.008	1.049	1.040	0.968	1.005	1.038	0.988	1.027	1.039
2003	1.008	1.067	1.059	1.017	1.078	1.060	1.013	1.072	1.059
2004	0.975	0.969	0.993	1.001	1.039	1.038	0.988	1.004	1.016
Geo-mean	0.990	1.015	1.025	0.993	1.027	1.034	0.994	1.021	1.027

Table A2. Parameter estimates from equation (10) for manufacturing, sector by sector, and energy intensive and non-energy intensive sectors.

Manufacturing

FE

Variable	Coefficient	Error	t-statistic	P-value
DLCO2TAX	0.475	0.036	13.198	[.000]
DLPF	0.179	0.012	14.591	[.000]
LFUELINT	0.505	0.021	24.395	[.000]
LKAPINT	-0.004	0.022	-0.186	[.852]
SIZEDUMMY1	-0.235	0.078	-3.019	[.003]
SIZEDUMMY2	-0.126	0.069	-1.841	[.066]
SIZEDUMMY3	-0.048	0.052	-0.927	[.354]
T	0.039	0.008	4.749	[.000]
T2	-0.002	0.000	-3.692	[.000]

Mining

FE

Variable	Coefficient	Error	t-statistic	P-value
DLCO2TAX	0.045	0.110	0.408	[.685]
DLPF	0.359	0.105	3.410	[.001]
LFUELINT	0.842	0.196	4.300	[.000]
LKAPINT	0.473	0.278	1.705	[.094]
SIZEDUMMY1	could	not	be	estimated
SIZEDUMMY2	0.559	0.810	0.690	[.493]
SIZEDUMMY3	-0.336	0.300	-1.119	[.267]
T	-0.111	0.096	-1.157	[.252]
T2	0.003	0.005	0.498	[.621]

Food

FE

Variable	Coefficient	Error	t-statistic	P-value
DLCO2TAX	0.210	0.094	2.224	[.026]
DLPF	0.040	0.020	2.041	[.042]
LFUELINT	0.464	0.069	6.761	[.000]
LKAPINT	0.004	0.037	0.113	[.910]
SIZEDUMMY1	-0.723	0.143	-5.069	[.000]
SIZEDUMMY2	-0.562	0.131	-4.289	[.000]
SIZEDUMMY3	-0.294	0.101	-2.907	[.004]
T	-0.054	0.021	-2.517	[.012]
T2	0.003	0.001	2.524	[.012]

Textile

FE

Variable	Coefficient	Error	t-statistic	P-value
DLCO2TAX	0.768	0.628	1.223	[.224]
DLPF	0.170	0.068	2.494	[.014]
LFUELINT	0.315	0.109	2.881	[.005]
LKAPINT	0.114	0.152	0.755	[.452]
SIZEDUMMY1	0.882	0.442	1.995	[.048]
SIZEDUMMY2	0.844	0.424	1.991	[.049]
SIZEDUMMY3	0.786	0.267	2.940	[.004]
T	0.062	0.055	1.113	[.268]
T2	-0.002	0.003	-0.840	[.403]

Wood

RE

Variable	Coefficient	Error	t-statistic	P-value
DLCO2TAX	0.567	0.036	15.804	[.000]
DLPF	0.348	0.053	6.510	[.000]
LFUELINT	0.168	0.039	4.344	[.000]
LKAPINT	0.007	0.042	0.170	[.865]
SIZEDUMMY1	-0.333	0.177	-1.885	[.059]
SIZEDUMMY2	-0.276	0.177	-1.554	[.120]
SIZEDUMMY3	-0.134	0.206	-0.651	[.515]
T	0.167	0.051	3.310	[.001]
T2	-0.011	0.003	-3.770	[.000]
C	0.375	0.428	0.876	[.381]

Pulp/paper

RE

Variable	Coefficient	Error	t-statistic	P-value
DLCO2TAX	0.313	0.034	9.124	[.000]
DLPF	0.062	0.023	2.693	[.007]
LFUELINT	0.065	0.024	2.734	[.006]
LKAPINT	-0.076	0.036	-2.131	[.033]
SIZEDUMMY1	0.129	0.079	1.641	[.101]
SIZEDUMMY2	0.034	0.082	0.416	[.677]
SIZEDUMMY3	0.122	0.088	1.383	[.167]
T	0.090	0.032	2.814	[.005]
T2	-0.006	0.002	-3.360	[.001]
C	0.458	0.285	1.608	[.108]

Printing

FE

Variable	Coefficient	Error	t-statistic	P-value
DLCO2TAX	0.044	0.156	0.279	[.781]
DLPF	0.194	0.048	4.018	[.000]
LFUELINT	0.409	0.097	4.197	[.000]
LKAPINT	-0.073	0.078	-0.946	[.345]
SIZEDUMMY1	-0.469	0.365	-1.286	[.200]
SIZEDUMMY2	-0.551	0.367	-1.501	[.135]
SIZEDUMMY3	-0.568	0.189	-2.996	[.003]
T	0.010	0.039	0.249	[.804]
T2	-0.002	0.002	-0.673	[.502]

Chemical

FE

Variable	Coefficient	Error	t-statistic	P-value
DLCO2TAX	0.529	0.286	1.852	[.066]
DLPF	0.110	0.048	2.296	[.023]
LFUELINT	0.526	0.091	5.806	[.000]
LKAPINT	0.065	0.100	0.649	[.517]
SIZEDUMMY1	0.168	0.267	0.630	[.530]
SIZEDUMMY2	0.228	0.254	0.898	[.370]
SIZEDUMMY3	0.361	0.280	1.288	[.199]
T	-0.088	0.058	-1.527	[.128]
T2	0.006	0.003	1.809	[.072]

Rubber/plastic

FE

Variable	Coefficient	Error	t-statistic	P-value
DLCO2TAX	0.355	0.157	2.262	[.024]
DLPF	0.147	0.041	3.567	[.000]
LFUELINT	0.556	0.071	7.875	[.000]
LKAPINT	0.046	0.064	0.706	[.481]
SIZEDUMMY1	-0.101	0.260	-0.390	[.697]
SIZEDUMMY2	0.062	0.252	0.245	[.807]
SIZEDUMMY3	0.232	0.143	1.620	[.106]
T	0.025	0.036	0.695	[.487]
T2	-0.001	0.002	-0.482	[.630]

Stone/mineral

FE

Variable	Coefficient	Error	t-statistic	P-value
DLCO2TAX	0.642	0.136	4.722	[.000]
DLPF	0.193	0.048	3.990	[.000]
LFUELINT	0.416	0.074	5.596	[.000]
LKAPINT	-0.051	0.075	-0.679	[.497]
SIZEDUMMY1	-0.309	0.230	-1.343	[.180]
SIZEDUMMY2	-0.326	0.174	-1.877	[.061]
SIZEDUMMY3	-0.230	0.134	-1.716	[.087]
T	-0.069	0.032	-2.143	[.033]
T2	0.004	0.002	2.173	[.030]

Iron/steel

FE

Variable	Coefficient	Error	t-statistic	P-value
DLCO2TAX	0.149	0.092	1.625	[.105]
DLPF	0.155	0.026	6.079	[.000]
LFUELINT	0.435	0.048	9.103	[.000]
LKAPINT	-0.032	0.052	-0.608	[.543]
SIZEDUMMY1	-0.110	0.140	-0.786	[.432]
SIZEDUMMY2	-0.005	0.124	-0.036	[.971]
SIZEDUMMY3	0.067	0.064	1.046	[.296]
T	0.012	0.020	0.576	[.565]
T2	-0.001	0.001	-0.814	[.416]

Machinery

FE

Variable	Coefficient	Error	t-statistic	P-value
DLCO2TAX	-0.040	0.066	-0.605	[.545]
DLPF	0.123	0.024	5.143	[.000]
LFUELINT	0.396	0.037	10.605	[.000]
LKAPINT	-0.019	0.050	-0.384	[.701]
SIZEDUMMY1	-0.080	0.147	-0.544	[.587]
SIZEDUMMY2	-0.057	0.110	-0.519	[.604]
SIZEDUMMY3	-0.011	0.085	-0.125	[.901]
T	0.054	0.019	2.889	[.004]
T2	-0.002	0.001	-1.956	[.051]

Electro

FE

Variable	Coefficient	Error	t-statistic	P-value
DLCO2TAX	-0.014	0.112	-0.122	[.903]
DLPF	0.131	0.037	3.590	[.000]
LFUELINT	0.413	0.123	3.359	[.001]
LKAPINT	0.015	0.085	0.171	[.864]
SIZEDUMMY1	-0.502	0.193	-2.603	[.010]
SIZEDUMMY2	-0.311	0.160	-1.944	[.053]
SIZEDUMMY3	-0.178	0.118	-1.516	[.130]
T	0.059	0.036	1.628	[.104]
T2	-0.002	0.002	-1.144	[.254]

Motor vehicles

FE

Variable	Coefficient	Error	t-statistic	P-value
DLCO2TAX	0.517	0.191	2.712	[.007]
DLPF	0.092	0.026	3.518	[.000]
LFUELINT	0.292	0.058	5.021	[.000]
LKAPINT	0.092	0.051	1.806	[.071]
SIZEDUMMY1	-0.450	0.204	-2.209	[.028]
SIZEDUMMY2	-0.215	0.187	-1.150	[.251]
SIZEDUMMY3	-0.119	0.146	-0.815	[.415]
T	0.012	0.031	0.373	[.709]
T2	0.000	0.002	0.073	[.942]

Energy intensive

FE

Variable	Coefficient	Error	t-statistic	P-value
DLCO2TAX	0.458	0.045	10.296	[.000]
DLPF	0.161	0.016	9.862	[.000]
LFUELINT	0.380	0.030	12.675	[.000]
LKAPINT	-0.045	0.034	-1.332	[.183]
SIZEDUMMY1	-0.091	0.107	-0.845	[.398]
SIZEDUMMY2	-0.060	0.097	-0.616	[.538]
SIZEDUMMY3	0.042	0.072	0.579	[.563]
T	0.018	0.015	1.188	[.235]
T2	-0.001	0.001	-1.688	[.091]

Non-energy intensive

FE

Variable	Coefficient	Error	t-statistic	P-value
DLCO2TAX	0.244	0.065	3.739	[.000]
DLPF	0.100	0.012	8.110	[.000]
LFUELINT	0.355	0.026	13.424	[.000]
LKAPINT	0.024	0.025	0.935	[.350]
SIZEDUMMY1	-0.415	0.081	-5.135	[.000]
SIZEDUMMY2	-0.311	0.072	-4.303	[.000]
SIZEDUMMY3	-0.181	0.055	-3.310	[.001]
T	0.018	0.011	1.583	[.113]
T2	-0.001	0.001	-0.888	[.374]